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Density-dependent dispersion in heterogeneous porous media Part II: Comparison with nonlinear models

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Abstract

The results of a series of high-resolution numerical experiments are used to test and compare three nonlinear models for high-concentration-gradient dispersion. Gravity stable miscible displacement is considered. The first model, introduced by Hassanizadeh, is a modification of Fick's law which involves a second-order term in the dispersive flux equation and an additional dispersion parameter β. The numerical experiments confirm the dependency of β on the flow rate. In addition, a dependency on travelled distance is observed. The model can successfully be applied to nearly homogeneous media ($\sigma^2 = 0.1$), but additional fitting is required for more heterogeneous media.

The second and third models are based on homogenization of the local scale equations describing density-dependent transport. Egorov considers media that are heterogeneous on the Darcy scale, whereas Demidov starts at the pore-scale level. Both approaches result in a macroscopic balance equation in which the dispersion coefficient is a function of the dimensionless density gradient. In addition, an expression for the concentration variance is derived. For small σ^2, Egorov's model predictions are in satisfactory agreement with the numerical experiments without the introduction of any new parameters. Demidov's model involves an additional fitting parameter, but can be applied to more heterogeneous media as well.

Keywords: Heterogeneous porous media; High-concentration-gradient dispersion; Brine transport; Homogenization; Solute transport; Density-dependent flow; Stochastic media; Macrodispersion; Concentration variance

1. Introduction

Numerous independent laboratory studies have been performed to assess the effect of high concentration and density gradients on hydrodynamic dispersion in porous media [1,4,5,12,14,15,19,22,24,25]. Several researchers who studied stable brine displacements in vertical columns concluded that linear Fick's law is inadequate for modelling the experiments beyond tracer concentrations (see e.g. Hassanizadeh and Leijnse [11], Schotting et al. [22], and Watson et al. [25]). However, other researchers conclude that the linear law is still applicable, but only when the value of the dispersivity is fitted to the experiments (see e.g. Bouhroum [5], or Jiao and Hötzl [13]). The observed dispersivity depends on both the density contrast between the fluids, and the mean flow rate in the column, and therefore varies from experiment to experiment. This is in contradiction with the basic premise that dispersivity is a medium property.

In Part I we discussed numerical experiments of brine displacements in vertical columns with small-scale heterogeneities. We showed that stabilizing gravity effects are

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